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Nonlocal Effects on D-branes in Plane-Wave Backgrounds

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We argue that the effective field theory on D3-branes in a plane-wave background with 3-form flux is a nonlocal deformation of Yang-Mills theory. In the case of NSNS flux, it is a dipole field theory with lightlike dipole vectors. For an RR 3-form flux the dipole theory is strongly coupled. We propose a weakly coupled S-dual description for it. The S-dual description is local at any finite order in string perturbation theory but becomes nonlocal when all perturbation theory orders are summed together.

String theory, AdS/CFT, pp-waves, nonlocality, dipole theory

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[1]$\langle 1|[1]|1\rangle$

[1]$\langle 1\rangle[1]\mathcal{N} = 1[1]diag(1)[2][1,2]$

[1]$\partial_1[1]\partial^1$

[1]$\mathbf{1}$

[1]L^1

[1]D_1^F

[1]$\mathbf{X}_1[1]\dot{\mathbf{X}}_1$

Introduction The restrictions imposed by the conditions of Lorentz invariance and locality play central roles in our understanding of the formal properties of quantum field theories. However, in string theory neither of these conditions appears to be fundamental. Thus, it is interesting to consider simple situations where they are relaxed. In particular, we will examine the properties of D-branes in certain plane-wave backgrounds with strong 3-form fields. As we will show in detail, the low energy effective theory describing the fluctuations of these D-branes is a non-local, Lorentz violating dipole theory Bergman:2000cw-Bergman:2001rw.

Typical interaction terms in the Lagrangian of this field theory are of the form $\int \phi_1(\vec{x})\phi_2(\vec{x}+\vec{L}_1)\phi_3(x+\vec{L}_1+\vec{L}_2)\cdots d^4\vec{x}$ where ϕ_i are fields and the $\vec{L}_i$ are fixed world-volume vectors. Roughly speaking, the non-locally coupled fields ϕ_i correspond to stretched open strings with end-points that are separated by $\vec{L}_i$ and with angular momentum along planes transverse to the brane. These strings are stabilized by the presence of strong 3-form fluxes with legs aligned along the dipole vectors as well as the plane of rotation Dasgupta:2000ry.

An exciting application of string theory with strong 3-form field strengths is the AdS_3/CFT_2 correspondence Maldacena:1997re. Unfortunately, progress had been limited by the fact that string theory in AdS backgrounds with RR field strengths are difficult to analyze exactly. However, the authors of Berenstein:2002jq have shown that a particularly tractable limit of the AdS/CFT correspondence can be obtained by taking the Penrose limit of type-IIB string theory on $AdS_5 \times S^5$ to obtain a plane-wave background. They were able to precisely match the properties of a certain subsector of 4 Super-Yang-Mills CFT (operators with large R-charge) with the exact results of Metsaev:2001bj-Russo:2002rq for strings in plane-wave backgrounds.

Similarly, one can consider the Penrose limits of $AdS_3 \times S^3 \times T^4$ Gomis:2002qi. As IIB has two three-form field strengths, H^1 (NSNS) and H^2 (RR), one finds a pair of models which are related by S-duality. The Penrose limit of the theory with H^1 flux is eqnarrayds$^2 = dx^+dx^- + \mu x^i x^i (dx^+)^2 - dx^a dx^a - dx^i dx^i, ppNSi$

In this paper we will study the interactions of the low energy effective theory of the D-brane excitations. We will show that N D3-brane probes of the plane-wave background (ppNSi)-(ppNSiii) are exactly described at low energies by a nonlocal $U(N)$ dipole gauge theory Bergman:2000cw with a lightlike dipole vector $\vec{L}$ proportional to μ.

A more complicated problem is the description of N D3-brane probes of the pp-wave background (ppRi)-(ppRiii), which has RR flux. It is related to the S-dual description of the lightlike dipole theory. We attack this problem by first studying the S-dual description of a $U(1)$ lightlike dipole theory and then guessing the generalization of that result to a $U(N)$ gauge group. We find that in any finite order of string perturbation theory the interactions of the D3-brane probes of the pp-wave background (ppRi)-(ppRiii) are local. Yet our result suggests that summing the local interactions to all orders in perturbation theory exhibits an intrinsic nonlocality with a characteristic length proportional to the string coupling constant, g_s.

The paper is organized as follows. In section secDT we review the definition and salient features of dipole theories. In section secLLppNS we identify the lightlike dipole theory as the low energy description of D3-branes in the pp-wave background (ppNSi)-(ppNSiii). In section secPropS we analyze the S-dual of the $U(1)$ lightlike dipole theories and conjecture an extension of the result to $U(N)$, We conclude in section secDisc with a list of possible extensions of our work.

Definition of dipole theories and their salient features secDT The dipole field theories that we will work with in this paper are nonlocal field theories that are deformations of 4 SYM. The Lagrangian of 4 SYM is eqnarray$L_4 = 1g^2 tr \left\{14F_{\mu\nu}F^{\mu\nu} + 12\sum_{I=1}^{6} D_\mu\Phi^I D^\mu\Phi^I + i\sum_{a=1}^{4} \overline{\psi}_a^{\dot\alpha}\sigma^{\mu\alpha}{}_{\dot\alpha} D_\mu\psi_\alpha^a\right\}$

The dipole theories are obtained from 4 SYM by the following steps (see Bergman:2001rw for more details): enumerate

D efine the complex linear combinations of the 6 scalar fields of (LagSYM):

$$Z_k \equiv \Phi_{2k-1} + i\Phi_{2k}, \qquad \overline{Z}_k \equiv \Phi_{2k-1} - i\Phi_{2k}, \qquad k = 1, 2, 3,$$

and assign a constant space-time 4-vector $\vec{L}_k$ to each scalar field Z_k.

M odify the covariant derivatives of the scalar fields so that $D_\mu Z_k$ at the space-time point x will be: equationdefDu $D_\mu Z_k(x) \equiv \mu Z_k(x) - iA_\mu(x - 12\vec{L}_k)Z_k(x) + iZ_k(x)A_\mu(x + 12\vec{L}_k)$.